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FORECASTING SYSTEMS TECHNICAL NOTE NO.11

THE IMPACT OF DROPSONDES ON ATLANTIC TROPICAL CYCLONE FORECAST TRACKS IN 1998

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MARCH 1999

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1. INTRODUCTION

In 1997 the NOAA Gulfstream-IV (G-IV) jet became available for 'synoptic surveillance' missions into the environment of developing tropical cyclones (TCs). This is in addition to NOAA P3 research aircraft which have been conducting dropsonde deployment into hurricanes for several years. The former can operate at flight levels near to the tropopause, whilst the latter fly at mid-tropospheric levels. Hence, G-IV dropsondes sample a much greater depth of the atmosphere.

1997 was an inactive hurricane season in the Atlantic and only five G-IV missions were flown. One was into weak Tropical Storm Claudette, two into Hurricane Erika and two into east Pacific Hurricane Linda. The impact of the dropsondes deployed during the latter four missions on UK Met. Office global model forecasts was assessed by Heming (1999). The impact was near to neutral in three of the cases, but significantly negative in the fourth. However, since there were so few cases, it is difficult to draw any conclusions on the usefulness of dropsonde data from these results.

1998 was an active hurricane season with 14 tropical storms of which 10 became hurricanes. 19 G-IV missions were flown during the season. Hence a much more comprehensive assessment of the usefulness of dropsonde data could be made. The results from this assessment are presented in this technical note.

2. IMPACT EXPERIMENTS

Table 1 gives the dates of the 19 G-IV missions and the TCs into which the missions were flown. Each mission usually lasted from about 18Z on the preceding day to 03Z on the nominal mission day. During this time up to 30 or so dropsondes were deployed in the environment of the TC. Research missions using P3 aircraft were also flown during G-IV missions and deployed dropsondes in the wider environment and near the core of the TC.

Several different strategies were considered for assessing the impact of these data. It was decided that the most useful strategy was to run several continuous experiments covering the most active phases of the season when many dropsondes were deployed. This means that the forecasts assessed are not only those which included G-IV dropsondes at the data time, but all intermediate forecasts between missions as well. In addition, the assessment was made of ***all*** dropsondes which includes those deployed by both the G-IV and P3 aircraft. This strategy allows the cumulative affect of the data to be assessed. The impact was also assessed on forecasts of TCs which occurred during the experiments, but were not directly targeted by the G-IV missions. e.g. the impact on Hurricanes Ivan, Jeanne and Karl was included in the

assessment even though missions at that time were targeted at Hurricane Georges only.

Table 2 gives details of the three experiments conducted and the G-IV missions which they covered. In each experiment a continuous assimilation cycle was adopted and a 5-day forecast run every 12 hours. Two identical versions of the model were run in each experiment, one including all dropsonde data (CNTL) and one excluding all dropsonde data (NODS). There were three G-IV missions not covered by the three experiments; one each into Tropical Storm Alex and Tropical Storm Hermine and the final mission into Hurricane Georges. The first two cases were weak storms which dissipated soon after the mission and the latter could not be rerun due to data archive problems.

3. VERIFICATION OF RESULTS

3.1 All Forecasts

Table 3 shows the track forecast verification for all forecasts for every Atlantic TC which occurred during the experiment periods. These results suggest that the impact of all dropsondes was relatively small and averages out at a 0.7% decrease in analysis/forecast error as a result of using dropsondes. The largest differences occurred at T+96 which showed a 5.2% decrease in error as a result of using dropsondes.

3.2 G-IV Forecasts only

In order to give a better idea of the impact of the G-IV dropsonde data, the 16 forecasts which were made at the nominal data time of G-IV missions were verified separately and the results found in Table 4. Note, the forecasts were not 'standalone', but were extracted from the continuous experiments which were conducted.

These results indicate that analysis errors and forecast errors up to T+72 were larger as a result of using dropsondes. However, errors were smaller at longer forecast ranges. A comparison of Tables 3 and 4 indicates that the impact of dropsondes on the cases when G-IV missions were flown is slightly less favourable than on all cases combined.

3.3 Individual Hurricanes

Tables 5-9 show the verification statistics for each individual hurricane targeted by G-IV missions. These show some marked variations in impact. The impact on forecasts of Hurricane Bonnie was positive at all forecast times except T+48. Despite larger analysis errors, the impact of dropsondes on forecasts of Hurricane Danielle was significantly positive (7-10% reduction in error). The results for Hurricane Earl were mixed and include a relatively small number of cases since the hurricane was fairly short-lived. In marked contrast to results for Hurricane Danielle, the impact of dropsondes on forecasts for

Hurricane Georges was consistently negative (24% increase in analysis error and 1-12% increase in forecast error). For Hurricane Mitch the results were also predominantly negative, but only three forecasts were rerun and the results were dominated by one of these forecasts (see section 4.2).

4. INDIVIDUAL CASES

Track plots were examined for every forecast which was rerun for the five hurricanes targeted by G-IV missions. These showed that in the vast majority of cases, the impact of the dropsonde data on the forecast track was relatively small. There were just two forecasts which produced large differences between the CNTL and NODS forecast tracks.

4.1 Hurricane Bonnie DT 00Z 24 August 1998

Figure 1 shows the forecast tracks for this case. The circles are CNTL (dropsondes included) forecast positions and squares the NODS (dropsondes excluded) forecast positions. Note, the NODS positions are only shown up to T+96 as the T+120 position was extra-tropical in mid-Atlantic.

The NODS forecast positions were almost perfect at T+24 and T+48, whilst the CNTL positions were to the left of the actual track. However, at T+72 the CNTL run correctly predicted landfall (although further south than actually occurred) whereas the NODS run predicted recurvature before reaching land, followed by a rapid acceleration into the Atlantic and extra-tropical transition by T+120. Figure 2 shows the distribution of dropsondes around the hurricane during the time window from about 18UTC 23 August to 03UTC 24 August. Not all dropsondes were successfully stored in the MetDB, so only a subset were available for use by the model. Dropsondes were deployed both in the environment into which the hurricane was expected to move and around the core of the system itself. The 850hPa vector wind differences between the CNTL and NODS analyses (Figure 3) indicates a strengthening of the wind in the CNTL analysis on the northern and eastern flanks of the hurricane as well as an increase in anti-cyclonic flow to the north of the hurricane. This is similar to results for Hurricane Erika in 1997 (see Heming, 1999). The stronger wind on the poleward side of the hurricane and strengthened ridge to the north produce a greater westward component of movement and a delay in the timing of recurvature of the hurricane seen in the subsequent CNTL forecast (Figure 1).

Figure 4 shows the T+96 forecasts for this run and shows the huge impact dropsondes had on the track of the hurricane in this case. The CNTL run has the centre just inland over South Carolina/Georgia whereas the NODS run has an almost extra-tropical system racing north-eastwards south of Nova Scotia. The actual location of the hurricane was over Cape Hatteras; much closer to the CNTL forecast position.

4.2 Hurricane Mitch DT 00Z 25 October 1998

Figure 5 shows the forecast tracks for this case. The circles are CNTL forecast positions and squares the NODS positions. The CNTL forecast track is much slower than the NODS. By T+120 the forecast centre is well offshore to the north-east of Honduras. However, the NODS forecast position is much closer to the coast and to the verifying location which was just onshore at the time. Hence, dropsondes had a marked negative impact on this forecast.

Figures 6 and 7 show the dropsonde distribution near to the analysis time and the 700hPa vector wind differences between the CNTL and NODS analyses. The latter clearly shows that the CNTL analysis has weaker winds on the northern flank of the hurricane and also has an area of greater cyclonic circulation near the Bahamas. Both of these effects would act to reduce the westward component of motion compared to the NODS run.

5. DISCUSSION and SUMMARY

A comprehensive assessment of the impact of dropsondes on the forecasts of Atlantic TCs in 1998 has been undertaken. Overall, the impact was found to be a very small positive one, but with some marked variations from one TC to the next.

Heming (1999) concluded that in 1997 dropsondes had the effect of strengthening the subtropical ridge on the poleward side of the TC in the global model analysis and subsequent forecast which had the effect of producing a slower and more westerly component to motion. The dropsonde sampling strategy may have played a major part in this, since it was not symmetric in all quadrants around the TC in any of the cases. Aberson (1999) recognised both the practical problems with and importance of the sampling strategy if dropsondes are to be effectively used in numerical models and that asymmetric sampling may have contributed to the impact seen in these cases.

Examination of the cases in the 1998 season indicate that the sampling strategy was still not ideal or symmetric in several cases. Figure 8 shows the CNTL and NODS forecast tracks for DT 00UTC 22 September for Hurricane Georges. The G-IV dropsondes deployed at this time were all between latitudes 24°N and 38°N. Presumably, this strategy was employed since most global model forecasts up to this point were indicating a north-westward movement and possible recurvature into this region. The CNTL forecast in this case has a greater westward component than the NODS forecast. This may be due to the strengthening of the subtropical ridge in the model produced by dropsonde deployment in the north-west quadrant as was seen in the 1997 cases. Figure 9 shows the forecasts from 24 hours later. This time the NODS forecast has a more westward component in its forecast track than the CNTL forecast. Examination of the G-IV dropsonde sampling for this case indicates a complete change in strategy from 24 hours previously with half of the sondes being

dropped to the south of the hurricane between 14°N and 19°N. It is speculated that the change in strategy is responsible for the reversal in the bias of the CNTL and NODS forecasts, although this cannot be verified by experiment as selective rejection of dropsondes is not possible.

The results in sections 3.1 and 3.2 raise another interesting question. Dropsondes have had a more positive impact on all forecasts across the whole experiment period than just on the individual cases which were targeted by G-IV missions. This suggests that dropsondes are of greater value across a wider environment and over longer timescales than they are close to the targeted area in the forecast immediately following deployment.

The large impact in the Hurricane Bonnie case (section 4.1) also raises an issue. Short range forecasts were worse as a result of using the dropsondes, but longer range forecasts were much better. Chan and Kwok (1997) found that the quality of short range forecasts are strongly influenced by the initial position and inner structure of the TC, whilst longer range forecasts were influenced more by the broader environment around the TC in the model. Figure 2 shows that dropsondes were deployed both near the core of the hurricane and in its wider environment. The inference could therefore be drawn that the inner core dropsondes were responsible for the worsening of short range forecasts, whilst the dropsondes further from the centre contributed to the better forecasts at longer ranges. Again, this is a speculative assertion which cannot be verified without further experimentation. However, it is believed by Sim Aberson and James Franklin (Hurricane Research Division, personal communication) that inner core or eyewall dropsondes are not appropriate for usage in global forecast models since they measure fine detail of the hurricane core. Assimilation schemes in global models are likely to spread this information too widely across the centre of the hurricane which may result in a poor representation of the hurricane in the model. On the basis of this, steps are being taken in 1999 to prevent eyewall dropsondes being assimilated into global model forecasts.

6. REFERENCES

Aberson, S.D. (1999). Targeting and Sampling Strategies to Improve Hurricane Forecasts. *23rd Conference on Hurricanes and Tropical Meteorology (Dallas, Texas, USA)*, pp. 105-106.

Chan, J.C.L. & Kwok, R.H.F. (1997). A Diagnostic Study on the Improvement in Tropical Cyclone Motion Prediction by the UK Meteorological Office Global Model. *Met. Apps*, **4**, pp.1-9.

Heming, J.T. (1999). The Impact of Dropsondes on UK Meteorological Office Global Model Forecasts of Hurricanes Erika and Linda. *23rd Conference on Hurricanes and Tropical Meteorology (Dallas, Texas, USA)*, pp. 830-833.

SUMMARY OF FIGURES

Figure 1 Observed and forecast tracks of Hurricane Bonnie, DT 00UTC, 24 August 1998. Circles indicate the CNTL forecast, squares the NODS forecast.

Figure 2 Dropsonde deployment around Hurricane Bonnie near to 00UTC 24 August 1998. Squares indicates sondes used by the model.

Figure 3 850hPa vector wind difference between CNTL and NODS analysis at 00UTC 24 August 1998.

Figure 4 Hurricane Bonnie CNTL and NODS T+96 forecasts, DT 00UTC 24 August 1998.

Figure 5 Observed and forecast tracks of Hurricane Mitch, DT 00UTC, 25 October 1998. Circles indicate the CNTL forecast, squares the NODS forecast.

Figure 6 Dropsonde deployment around Hurricane Mitch near to 00UTC 25 October 1998. Squares indicates sondes used by the model.

Figure 7 700hPa vector wind difference between CNTL and NODS analysis at 00UTC 25 October 1998.

Figure 8 Observed and forecast tracks of Hurricane Georges, DT 00UTC, 22 September 1998. Circles indicate the CNTL forecast, squares the NODS forecast.

Figure 9 Observed and forecast tracks of Hurricane Georges, DT 00UTC, 23 September 1998. Circles indicate the CNTL forecast, squares the NODS forecast.

Storm name	Nominal mission time (yymmdd). All at 00UTC
Alex	980801
Bonnie	980821, 980822, 980824, 980825
Danielle	980829, 980830, 980831
Earl	980902
Hermine	980917
Georges	980919, 980920, 980922, 980923, 980924, 980926, 980927
Mitch	981025, 981026

Missions last from approximately 18UTC the preceding day to 03UTC on the nominal mission day.

Table 1
Details of G-IV Missions in 1998

Experiment number	Start and end dates	Tropical cyclones and number of G-IV missions flown (in brackets)
1	00UTC 980821 to 12UTC 980902	Bonnie (4), Charley (0*), Danielle (3), Earl (1)
2	00UTC 980919 to 12UTC 980926	Georges (6), Ivan (0*), Jeanne (0*), Karl (0*)
3	00UTC 981025 to 00UTC 981026	Mitch (2)

(0*) G-IV missions did not target these TCs, but the impact of dropsonde data on their forecasts is included in the assessment.

Table 2
Details of Experiments

	T+0	T+24	T+48	T+72	T+96	T+120
No. of cases	89	84	75	63	49	32
NODS error (km)	42	137	248	377	498	739
CNTL error (km)	42	136	250	373	472	749
Error reduction *(%)	0.0	0.7	-0.8	1.1	5.2	-1.4

* of CNTL (with dropsondes) relative to NODS (no dropsondes)

Mean results:
Total number of cases: 392
Analysis/Forecast track error ***decrease***: 0.7%

Table 3
Verification of All Experiments

	T+0	T+24	T+48	T+72	T+96	T+120
No. of cases	16	16	15	15	13	9
NODS error (km)	38	132	211	316	589	918
CNTL error (km)	43	133	214	320	548	910
Error reduction *(%)	-13.2	-0.8	-1.4	-1.3	7.0	0.9

* of CNTL (with dropsondes) relative to NODS (no dropsondes)

Mean results:
Total number of cases: 84
Analysis/Forecast track error ***increase***: 1.8%

Table 4
Verification of G-IV cases only

	T+0	T+24	T+48	T+72	T+96	T+120
No. of cases	20	17	15	13	11	8
NODS error (km)	54	122	221	267	590	1000
CNTL error (km)	46	119	230	248	434	941
Error reduction *(%)	14.8	2.5	-4.1	7.1	26.4	5.9

* of CNTL (with dropsondes) relative to NODS (no dropsondes)

Mean results:
Total number of cases: 84
Analysis/Forecast track error ***decrease***: 8.4%

Table 5
Verification of Hurricane Bonnie cases only

	T+0	T+24	T+48	T+72	T+96	T+120
No. of cases	18	18	16	13	10	3
NODS error (km)	32	89	226	436	778	836
CNTL error (km)	34	80	210	395	706	754
Error reduction *(%)	-6.3	10.1	7.1	9.4	9.3	9.8

* of CNTL (with dropsondes) relative to NODS (no dropsondes)

Mean results:
Total number of cases: 78
Analysis/Forecast track error ***decrease***: 5.5%

Table 6
Verification of Hurricane Danielle cases only

	T+0	T+24	T+48	T+72	T+96	T+120
No. of cases	4	4	2	-	-	-
NODS error (km)	112	297	556	-	-	-
CNTL error (km)	106	290	573	-	-	-
Error reduction *(%)	5.5	2.4	-3.1	-	-	-

* of CNTL (with dropsondes) relative to NODS (no dropsondes)

Mean results:
Total number of cases: 10
Analysis/Forecast track error ***decrease***: 2.5%

Table 7
Verification of Hurricane Earl cases only

	T+0	T+24	T+48	T+72	T+96	T+120
No. of cases	16	16	16	15	13	9
NODS error (km)	37	128	223	295	445	932
CNTL error (km)	46	131	226	316	498	972
Error reduction *(%)	-24.3	-2.3	-1.3	-7.1	-12.1	-4.3

* of CNTL (with dropsondes) relative to NODS (no dropsondes)

Mean results:
Total number of cases: 85
Analysis/Forecast track error ***increase***: 8.8%

Table 8
Verification of Hurricane Georges cases only

	T+0	T+24	T+48	T+72	T+96	T+120
No. of cases	3	3	3	3	3	3
NODS error (km)	23	105	179	242	290	376
CNTL error (km)	28	100	200	287	369	452
Error reduction *(%)	-21.7	4.5	-11.7	-18.6	-32.6	-20.2

* of CNTL (with dropsondes) relative to NODS (no dropsondes)

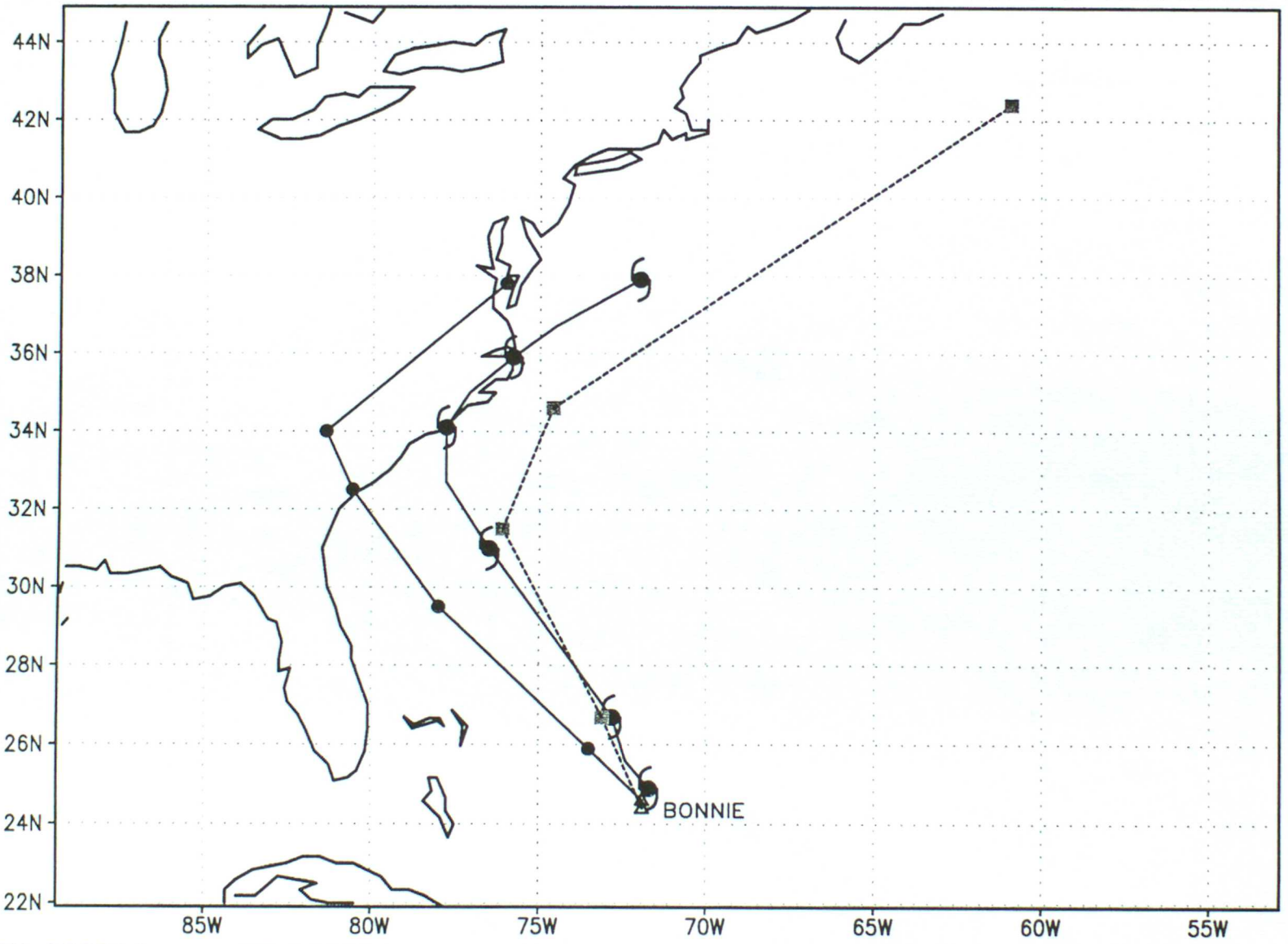
Mean results:
Total number of cases: 18
Analysis/Forecast track error ***increase***: 16.7%

Table 9
Verification of Hurricane Mitch cases only

Figure 1

CONTROL and TEST

FORECAST TRACKS of HURRICANE BONNIE



CN 980824 --- TE 980824

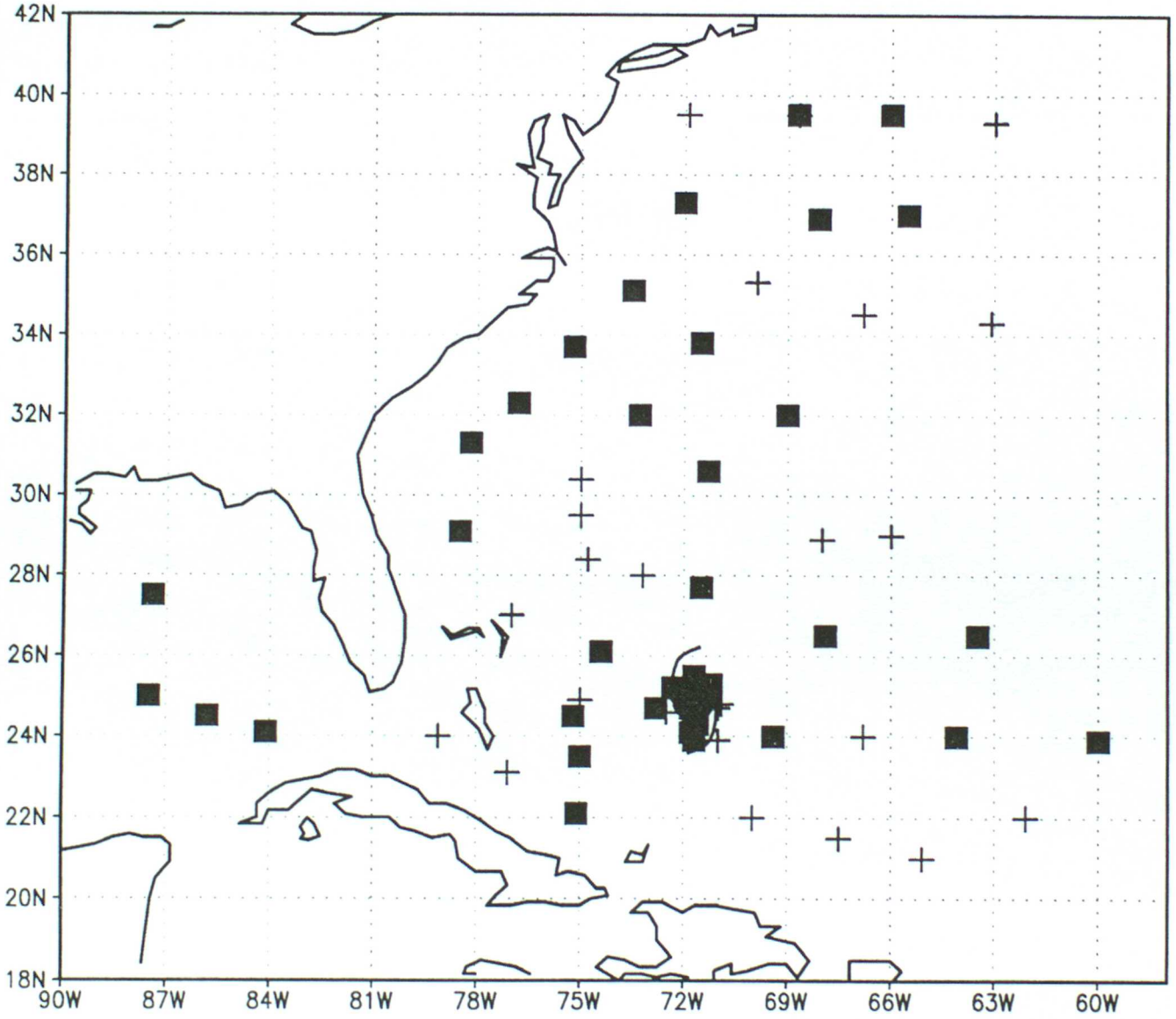
KEY to FORECAST TRACKS

(Triangles denote analysed positions)

24 HOURLY REAL TIME OBSERVED POSITIONS

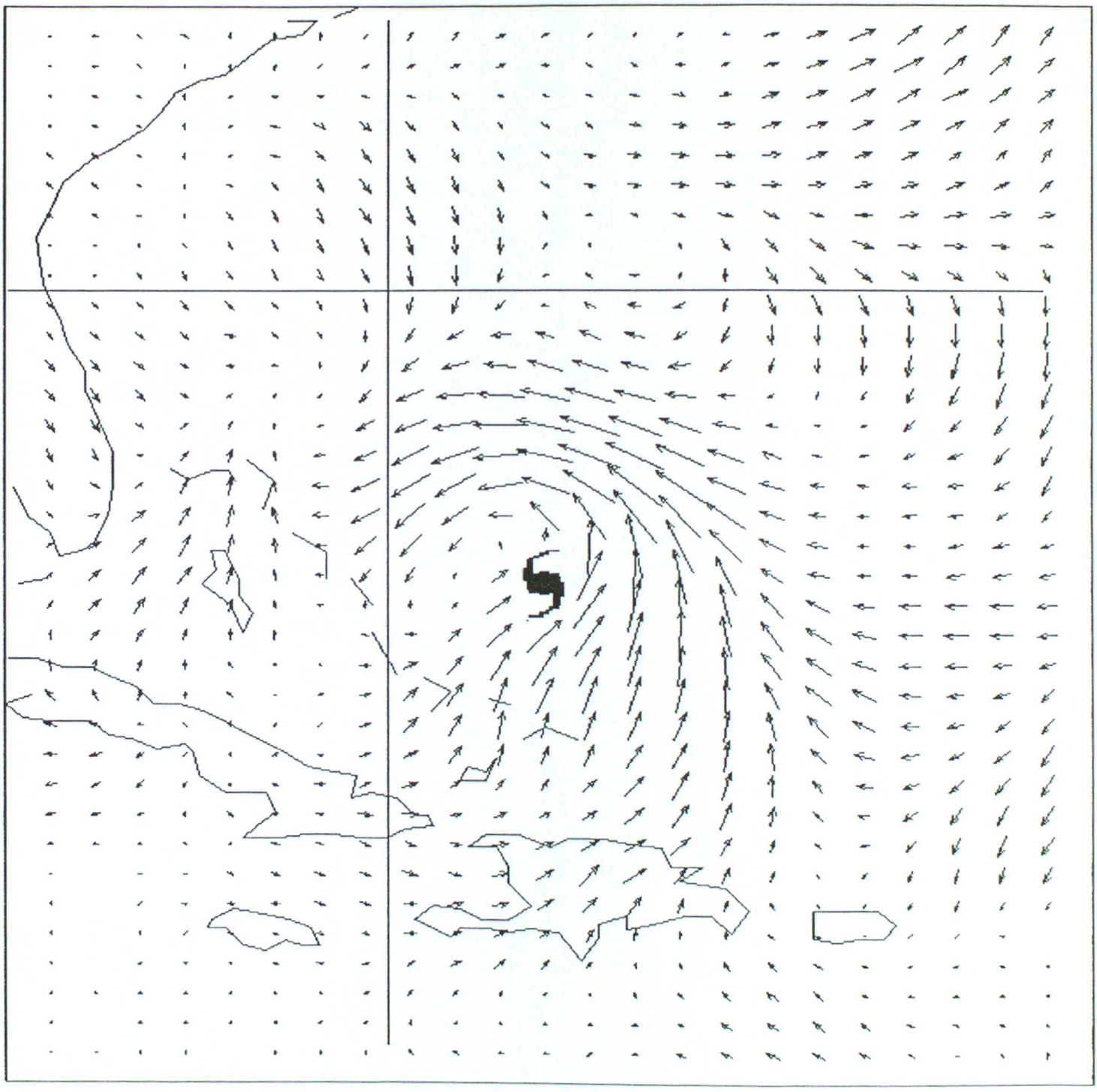
DATE/TIME OF FIRST SYMBOL 00Z 24 AUGUST 1998

Figure 2
DROPSONDE DISTRIBUTION



DT 00UTC 24 August 1998
Squares: Dropsondes used by model
Crosses: Dropsondes not used by model

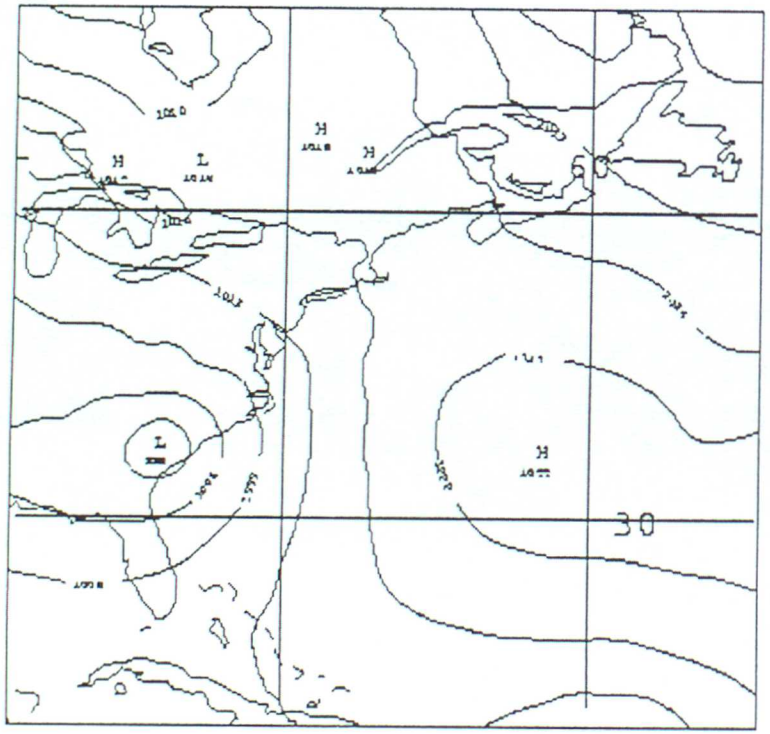
Figure 3
850hPa Vector Wind Analysis Differences
DT 00UTC 24 August 1998



→ REPRESENTS 2 M/S

Figure 4 Hurricane Bonnie T+96 forecasts
DT 00UTC 24 August 1998

With dropsondes



Without dropsondes

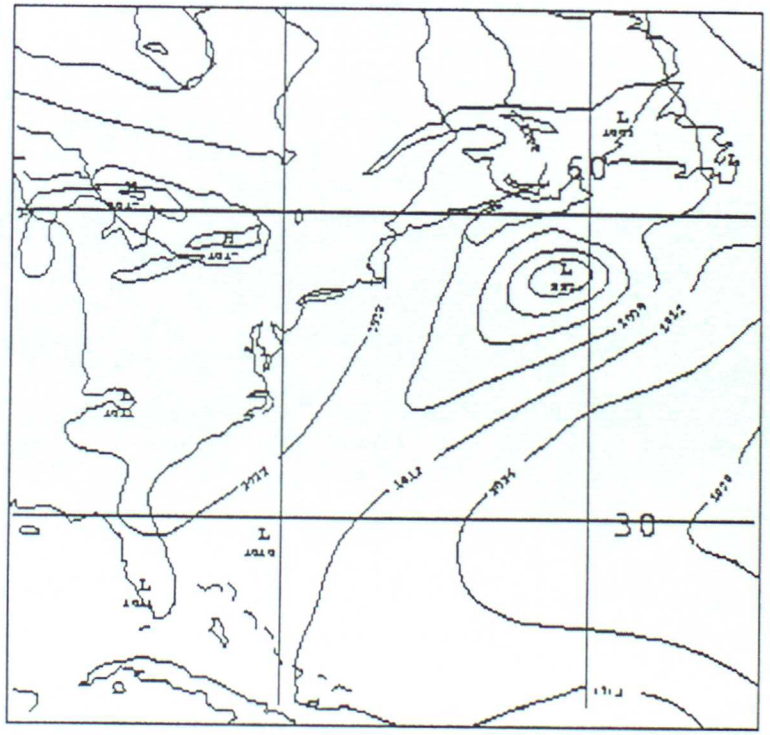
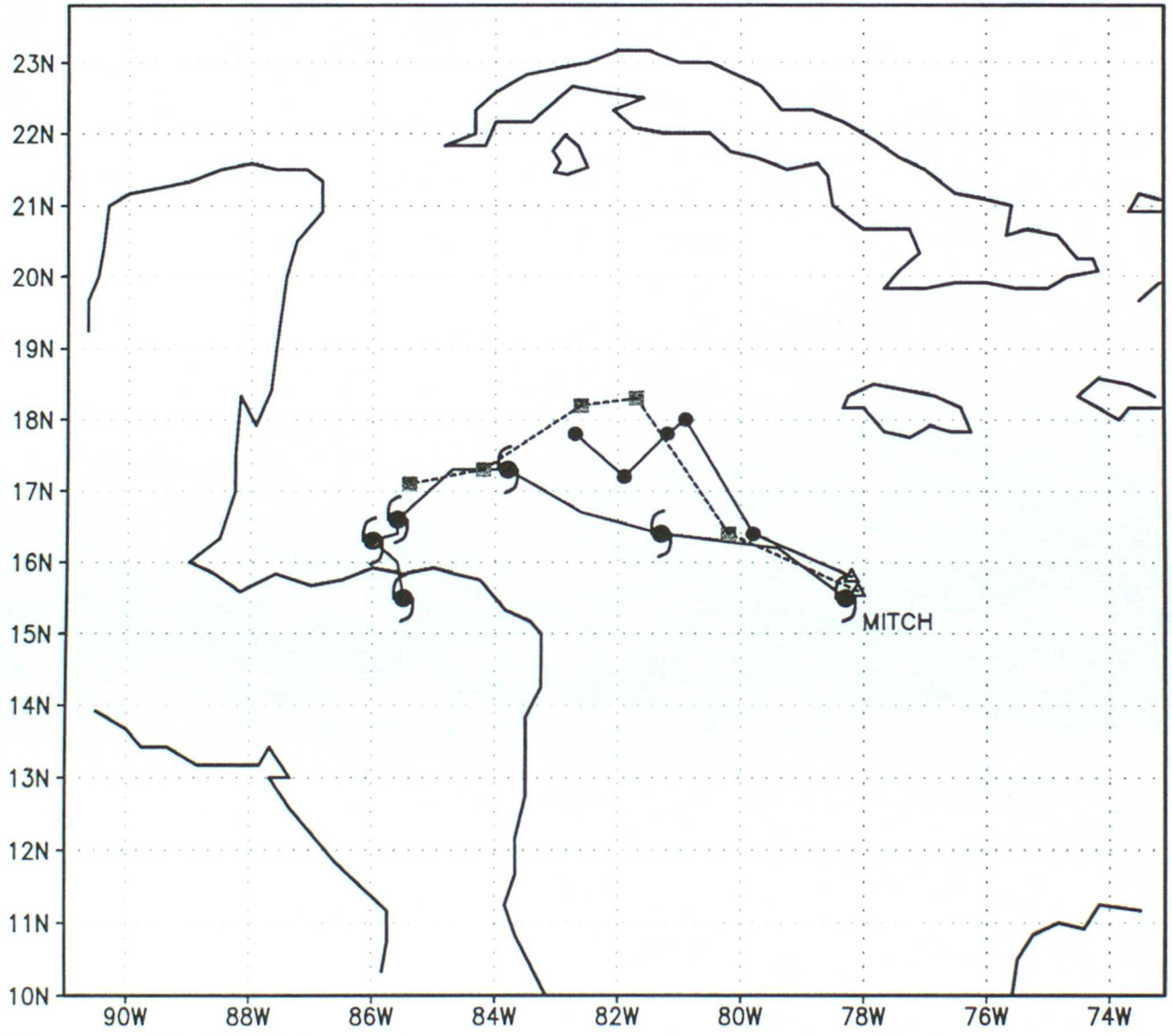


Figure 5

CONTROL and TEST FORECAST TRACKS of HURRICANE MITCH



CN 981025 TE 981025

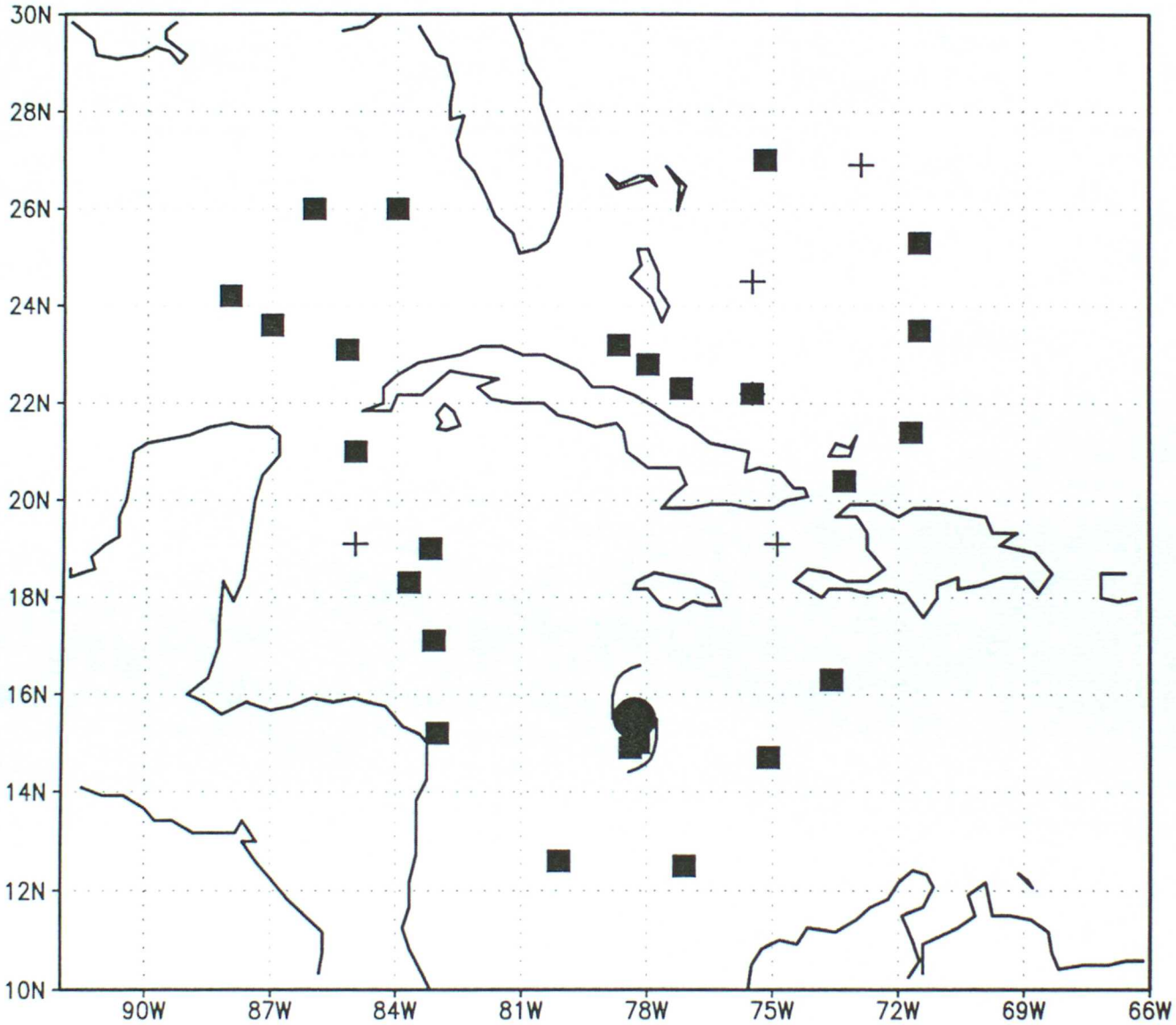
KEY to FORECAST TRACKS

(Triangles denote analysed positions)

24 HOURLY REAL TIME OBSERVED POSITIONS

DATE/TIME OF FIRST SYMBOL 00Z 25 OCTOBER 1998

Figure 6
DROPSONDE DISTRIBUTION



DT 00UTC 25 October 1998
Squares: Dropsondes used by model
Crosses: Dropsondes not used by model

Figure 7
700hPa Vector Wind Analysis Differences
DT 00UTC 25 October 1998

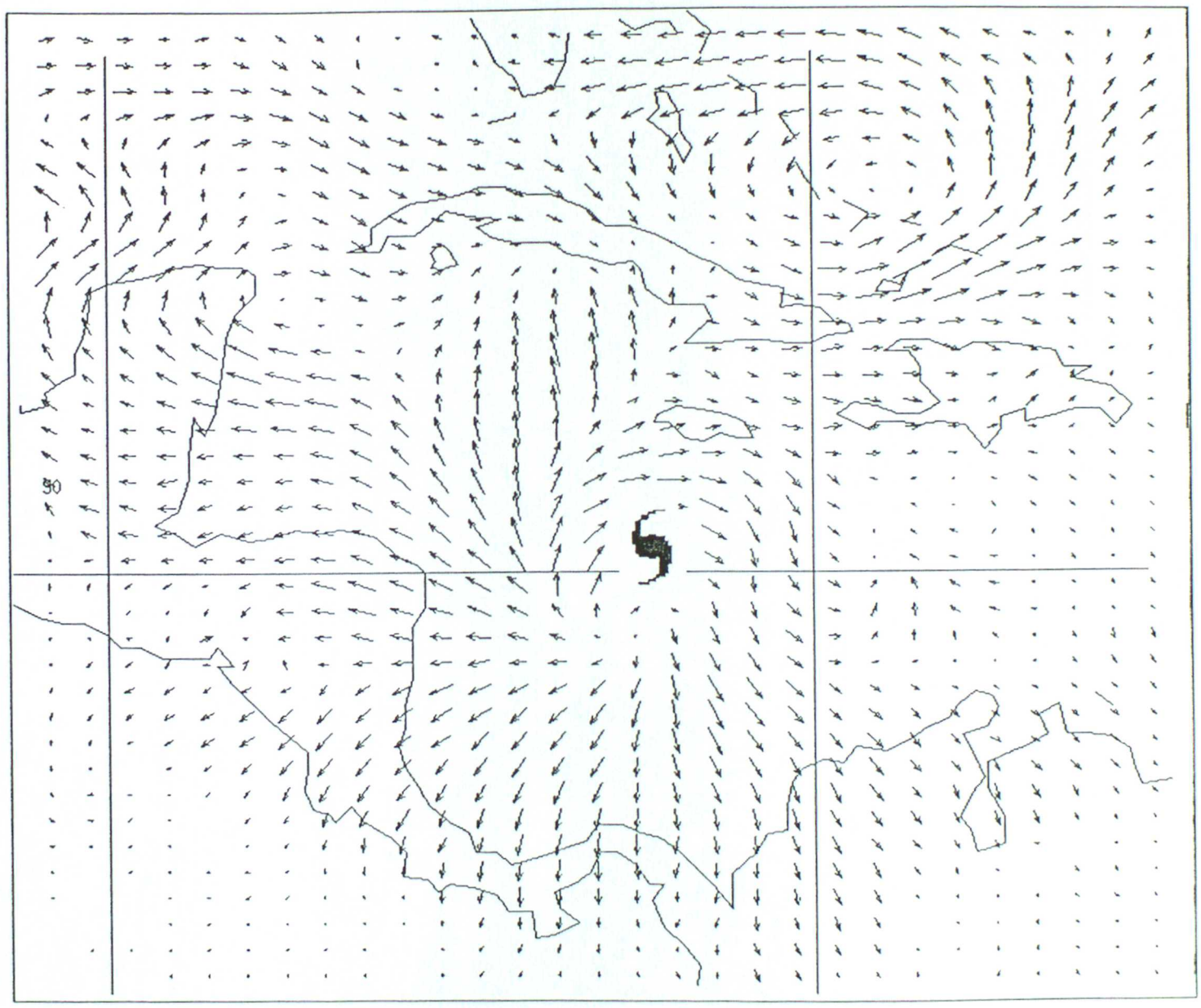
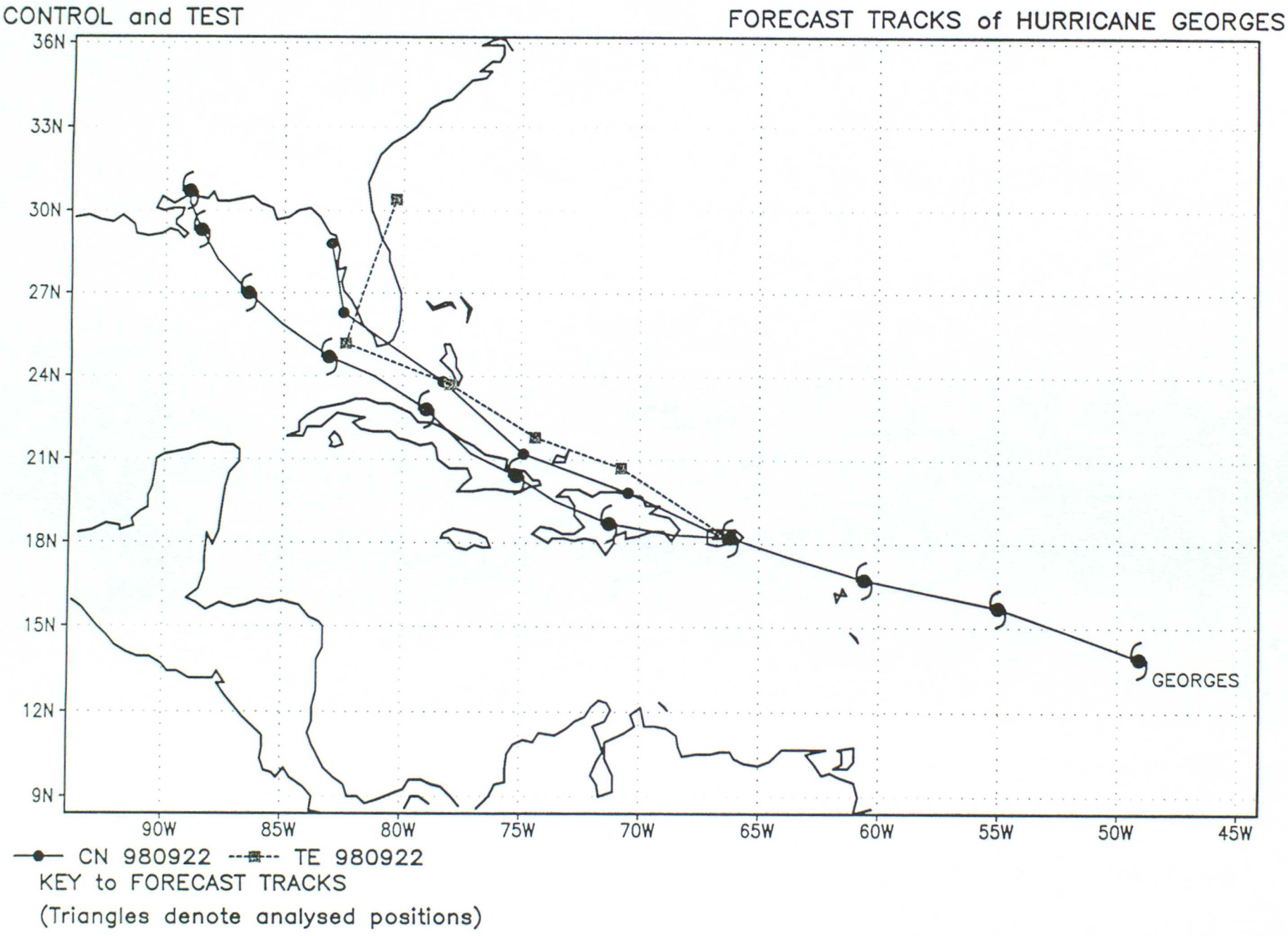


Figure 8


CONTROL and TEST
FORECAST TRACKS of HURRICANE GEORGES
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33N
30N
27N
24N
21N
18N
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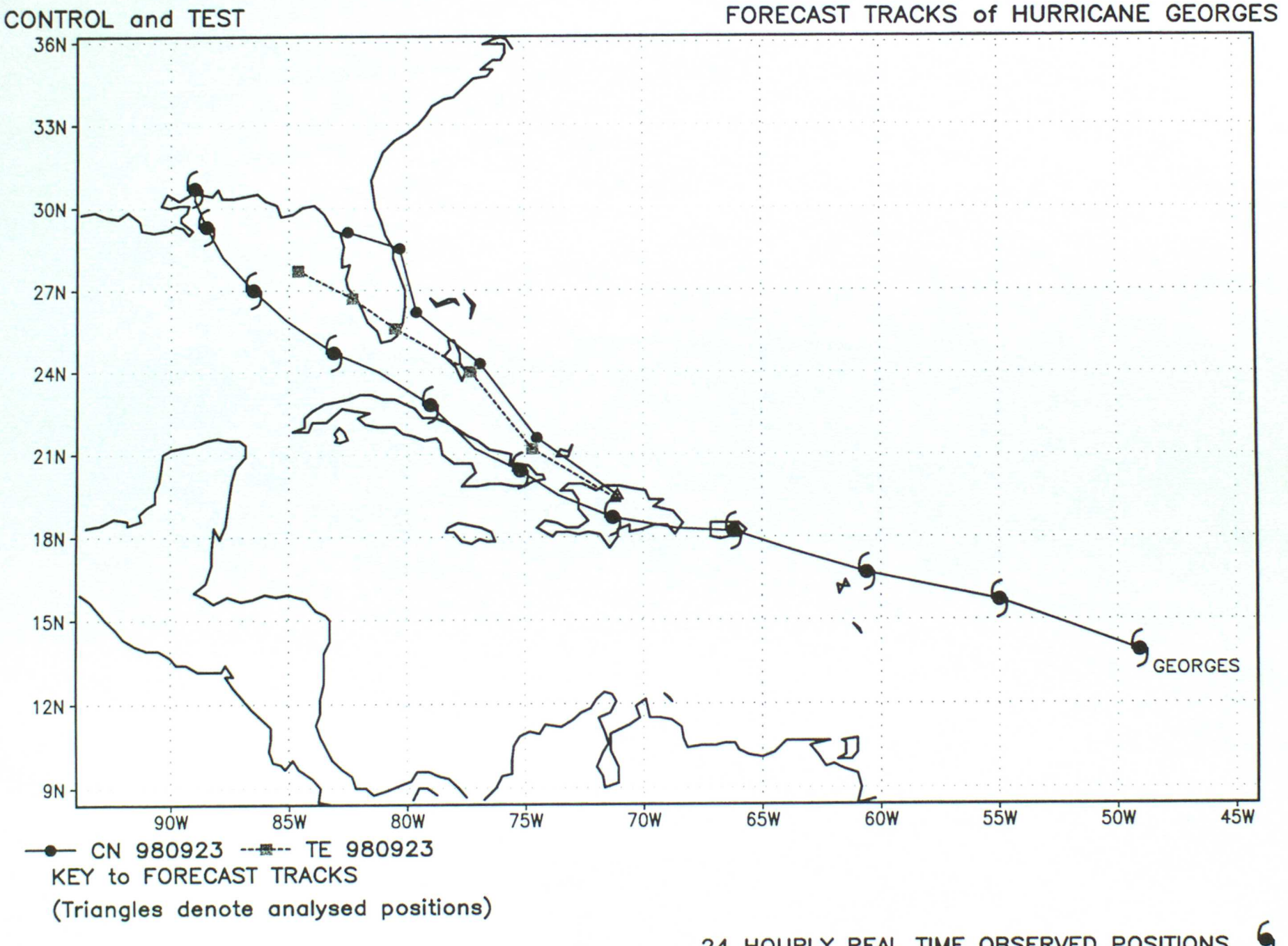
12N
9N
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
GEORGES
CN 980922
TE 980922
KEY to FORECAST TRACKS
(Triangles denote analysed positions)
24 HOURLY REAL TIME OBSERVED POSITIONS
DATE/TIME OF FIRST SYMBOL 00Z 19 SEPTEMBER 1998

Figure 9


CONTROL and TEST
FORECAST TRACKS of HURRICANE GEORGES
36N
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18N
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9N
90W
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80W
75W
70W
65W
60W
55W
50W
45W
GEORGES
CN 980923
TE 980923
KEY to FORECAST TRACKS
(Triangles denote analysed positions)
24 HOURLY REAL TIME OBSERVED POSITIONS
DATE/TIME OF FIRST SYMBOL 00Z 19 SEPTEMBER 1998